

OBSERVING THE IN-SITU BEHAVIOUR OF SERIES AND PARALLEL VAV-FAN
POWERED TERMINAL UNITS

A Thesis

by

BASEL HAMDI KANAAN

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Chair of Committee,	John Bryant
Committee Members,	Michael Pate
	Manish Dixit

Head of Department,	Joe Horlan
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ABSTRACT

This study investigated multiple aspects related to how fan powered terminal units (FPTU), as used in variable air volume systems, behave under as-built conditions. Whether this behavior conforms to accepted industry norms and expectations and how existing energy simulation tools react to a variety of input extremes based on program “defaults” and “rules of thumb”.

The efforts by the Air-Conditioning, Heating and Refrigeration Institute to update existing energy models of FPTU’s raised the issue of quantifying the static pressure rise observed across FPTU’s. This study has corroborated existing laboratory results with in-situ “field” measurements ranging between 0.2 in. w.g. (50 Pa) to 0.27 in. w.g. (67.2 Pa).

The in-situ measurements were expanded to include qualitative analyses of series and parallel FPTU leakage. The study demonstrated – through observing temperature differences between the surround plenum and fan powered terminal unit induction port – that there is no significant evidence of series FPTU leakage, while a single parallel FPTU was observed to have leaked. Coupling that data set with infrared (IR) images captured of pressurized parallel fan powered terminal units (usually considered normal operating conditions for parallel FPTU’s) showing evidence of leakage along the FPTU “seams”, induction port and interface connections.

The in-situ measurement also determined that “field” FPTU’s operate under lower downstream static pressure conditions than those set by AHRI/ANSI 880. Ranging from 0.0417 in. w.g. (10.4 Pa) to 0.1014 in. w.g. (25.2 Pa).

Previous research efforts independently quantified the two major inputs EnergyPlus requires to simulate fan powered terminal units (static pressure rise across the FPTU and motor efficiency). This study was expanded and aimed to determine which combination of the two inputs – either within the quantified parameters or a combination of more extreme cases – contributed to observable differences in energy consumption. The study concluded that the overall energy consumed by the simulated system does not change significantly, an observed difference of 2.3% annually between the greater extremes.

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The energy simulation used in chapter two was compiled and provided by Dr. Dennis O’Neal and Dr. Peng Yin of Baylor University.

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NOMENCLATURE

AHRI	Air-Conditioning, Heating and Refrigeration Institute
ASHRAE	American Society of Heating, Refrigerating and Air-conditioning Engineers
BMS	Building Management System
FPTU	Fan Powered Terminal Unit
PIU	Powered Induction Unit
TAMU	Texas A&M University
VAV	Variable Air Volume

TABLE OF CONTENTS

	Page
ABSTRACT.....	ii
ACKNOWLEDGEMENTS.....	iii
CONTRIBUTORS AND FUNDING SOURCES.....	iv
NOMENCLATURE.....	v
TABLE OF CONTENTS.....	vi
LIST OF FIGURES.....	vii
LIST OF TABLES.....	ix
CHAPTER I INTRODUCTION AND LITERATURE REVIEW.....	1
Variable Air Volume Systems and Fan Powered Terminal Units.....	1
Series vs. Parallel Fan Power Consumption.....	4
Review of Literature.....	4
Problem Statement for Current Study.....	7
Research Objectives.....	7
Limitations.....	8
In-Situ Measurement Methodology.....	8
Energy Simulation Methodology.....	9
CHAPTER II ENERGY SIMULATION.....	11
Discussion.....	14
CHAPTER III EVIDENCE OF LEAKAGE FOR SERIES AND PARALLEL FPTU'S.....	16
Evidence of Leakage Through Observed Temperature Differences.....	16
Evidence of Leakage Through Infrared Observations.....	23
Discussion.....	25
CHAPTER IV DOWNSTREAM STATIC PRESSURE READINGS FOR FPTU'S.....	27
Discussion.....	32
CHAPTER V OBSERVED PRESSURE RISE ACROSS SERIES FPTU.....	34
Discussion.....	35
CHAPTER VI CONCLUSIONS AND FURTHER RESEARCH.....	36
REFERENCES.....	38

LIST OF FIGURES

	Page
Figure 1.1 Typical VAV system schematic.....	2
Figure 1.2 Series type FPTU.....	3
Figure 1.3 Series type FPTU.....	3
Figure 1.4 Proposed experimental setup.....	8
Figure 1.5 Energy model zones.....	9
Figure 2.1 Total energy consumed by FPTU's.....	12
Figure 2.2 Total heating energy.....	13
Figure 2.3 Total energy consumed by modeled HVAC system.....	14
Figure 3.1 TAMU Agrilife Extension Building (AGLS), Rm 129 (series FPTU) – temperature data.....	17
Figure 3.2 TAMU Agrilife Extension Building (AGLS), Rm 132 (series FPTU) – temperature data.....	18
Figure 3.3 TAMU Institute of Preclinical Studies (TIPS), Rm 2043 (series FPTU) – temperature data.....	19
Figure 3.4 TAMU Institute of Preclinical Studies (TIPS), auditorium (parallel FPTU) – temperature data.....	20
Figure 3.5 TAMU Institute of Preclinical Studies (TIPS), Conf. Rm B (series FPTU) – temperature data.....	21
Figure 3.6 TAMU Transportation Institute (TTI), entrance lobby (parallel FPTU) – temperature data.....	22
Figure 3.7 Induction port of a parallel FPTU.....	23
Figure 3.8 Plenum and induction port temperature images for parallel FPTU's.....	23
Figure 3.9 Access panel seam leakage in parallel FPTU.....	24
Figure 3.10 Construction seam leakage for a series FPTU.....	25
Figure 4.1 TAMU Agrilife Extension Building (AGLS), Rm 129 (series FPTU) – downstream static pressure.....	27
Figure 4.2 TAMU Agrilife Extension Building (AGLS), Rm 132 (series FPTU) – downstream static pressure.....	28

Figure 4.3 TAMU Institute of Preclinical Studies (TIPS), Rm 2043 (series FPTU) – downstream static pressure.....	29
Figure 4.4 TAMU Institute of Preclinical Studies (TIPS), auditorium (parallel FPTU) – downstream static pressure.....	30
Figure 4.5 TAMU Institute of Preclinical Studies (TIPS), Conf. Rm B (series FPTU) – downstream static pressure.....	31
Figure 4.6 TAMU Transportation Institute (TTI), entrance lobby (parallel FPTU) – downstream static pressure.....	32
Figure 5.1 TAMU Agrilife Extension Building (AGLS), Rm 132.....	34

LIST OF TABLES

	Page
Table 1.1 Summary of data points to be measured.....	9

CHAPTER I

INTRODUCTION AND LITERATURE REVIEW

The Air-conditioning, Heating and Refrigeration Institute (AHRI) sponsored work to update existing building energy simulation models that include the behavior and performance of series fan powered variable air volume terminal units (FPTU). Existing energy simulation models, such as EnergyPlus, rely on the following data points as inputs for modeling a series FPTU,

- Pressure rise across the terminal unit fan
- Efficiency of terminal unit fan

As part of the AHRI project, an initial study was performed on a series FPTU to determine measuring methodology and magnitude of differential pressure rise for the unit in an “as built” condition (Bryant and Bryant 2015). Research has also been conducted that provides more accurate modeling of terminal unit efficiencies (Yin and O’Neal, 2014a and b).

Both papers rely on experimental methods outlined by AHRI standard 880 which requires an experimental setup to maintain a downstream static pressure of 0.25in w.g. (62.21 Pa) or greater. This study investigated the stated requirement by AHRI standard 880 and evaluated that it is, indeed, representative of “real-world” use of series type fan powered variable air volume terminal units.

Variable Air Volume Systems and Fan Powered Terminal Units

Figure 1.1 shows a standard schematic for a variable air volume (VAV) air conditioning system whereby zone temperature control is achieved by varying the volume of airflow to the zone.

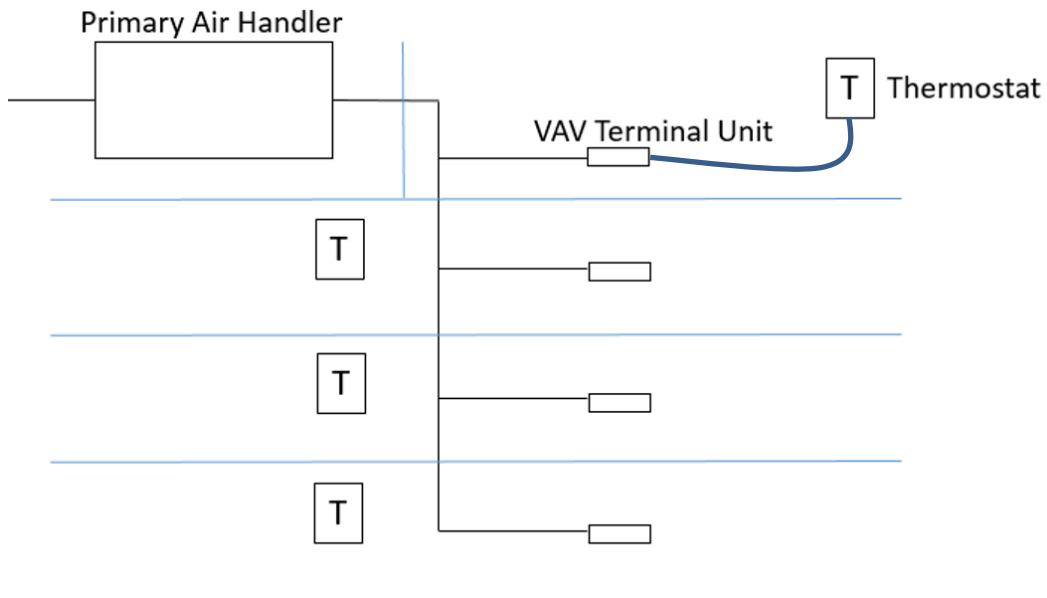


Figure 1.1. Typical VAV system schematic

The thermostat detects variations in temperatures in a given zone and through a control scheme, communicates the airflow requirements to the VAV terminal unit. The terminal unit, equipped with an air velocity measurement device, determines the required airflow and regulates the outgoing airflow to the zone through a volume control damper. Finally, the primary air handler responds to variations in air quantity demand by increasing or decreasing fan RPM and this is achieved through use of a variable frequency drive (VFD) on the fan motor.

A common variation of VAV terminal units is the addition of internal fans, and depending on the internal arrangement of the fans these are referred to as series or parallel type fan powered terminal units (FTPU's). In the EnergyPlus simulation program, these units are referred to as powered induction units (PIU's). Schematics of these units are shown in Figures 1.2 and 1.3 respectively.

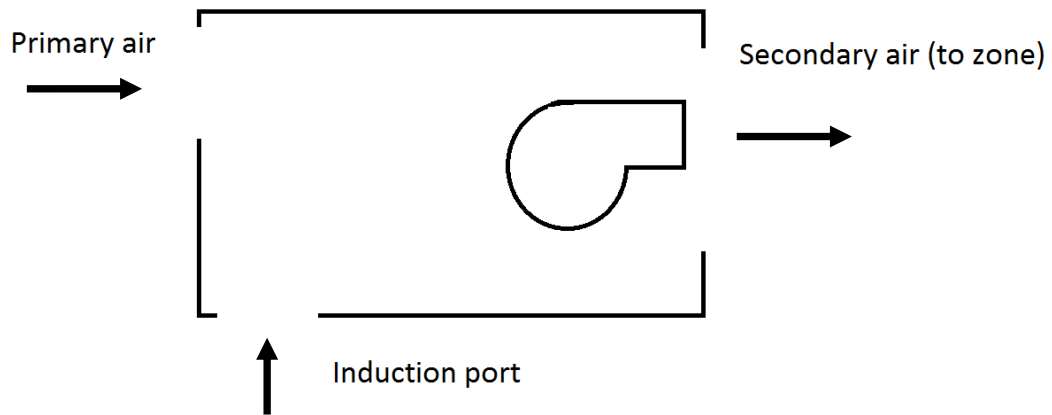


Figure 1.2. Series type FPTU

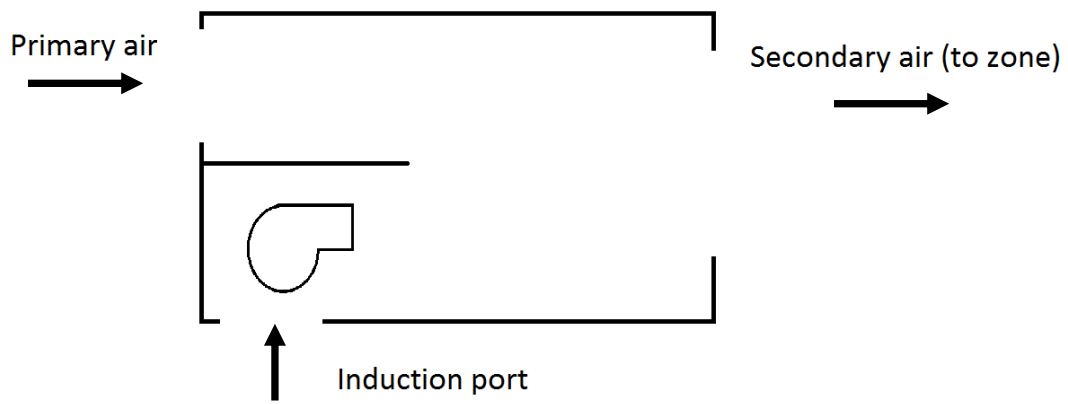


Figure 1.3. Parallel type FPTU

In a series FPTU, the terminal fan is located in series with the primary fan and the terminal fan runs continuously providing airflow to the secondary zone. Temperature is controlled by regulating primary airflow. A reduction in primary airflow will induce return plenum flow through the induction port and into the zone.

In a parallel FPTU, the terminal fan only operates when primary flow is at minimum and the zone requires supplemental heating. The terminal fan is located in the induction inlet parallel to the primary air inlet.

Series vs. Parallel Fan Power Consumption

It is commonly held that parallel FPTUs consume less power relative to series type terminal units operating under similar environmental and zone conditions. Series FPTUs are designed to operate continuously whereas parallel FPTU fans operate only when the serviced zone requires supplemental heat. By extension, the energy consumed by these small motors is higher in series than in parallel FPTUs.

However, (Bryant et al, 2010) suggested that if FPTU primary air leakage is included in the energy consumption model of parallel terminal units then their power consumption is comparable to that of series units. At high rates of primary air leakage from a parallel FPTU, approximately 20%, their model suggested that systems using series FPTU's will consume less energy than their parallel counterparts.

Parallel FPTUs operate under positive pressure relative to the plenum area because of fan positioning within the FPTU (when the terminal fan is running), it is thus expected to have a higher leakage factor relative to a series unit which is more likely to operate under negative pressure.

Review of Literature

ANSI/AHRI standard 880

ANSI/AHRI standard 880 establishes testing and data collection standards for air terminal units in order to certify performance data and insure manufacturer data conformity. Section 7.2 of the 2011 edition defines the standard rating condition for terminal unit integral fans as follows "7.2.1.2 Integral Fan. The fan airflow rating shall be established and published at 0.25 in. H₂O (62 Pa) discharge static pressure or minimum recommended pressure (whichever is greater) with any fan volume dampers at wide open position, and primary air damper closed."

Because of this standard, a majority of test setups for commercially available terminal units adhere to the conditions set. One purpose of this research proposal was to verify the validity of the standard with respect to "real world" installation and use of FPTUs.

Performance of VAV fan powered units: experimental setup and methodology

Bryant and Cramlet (2008a) described an experimental setup for FPTU's. Their study utilized a range of FPTU that represented the bulk of installed FPTUs used in the U.S. market.

The experimental study environmental conditions, measuring equipment, and data acquisition system adhered to test standards developed by ASHRAE and AHRI (ANSI/ASHRAE 130 and AHRI 880). The paper described a solid framework on which an experimental methodology and data acquisition setup may be designed, however the methodology must be tailored to accommodate the experiment objective, FPTU availability and on-site environmental conditions.

Performance of VAV series fan powered terminal units: experimental results and models

Utilizing the experimental setup and methodology developed in a previous study (Bryant & Cramlet 2008b) empirical models were developed for airflow output and power consumption for a set of series FPTUs.

Six terminal units were tested; three 8 in. (200 mm) units and three 12 in. (300 mm) units were provided by three different manufacturers. Data were collected for power consumption, airflow, upstream and downstream static pressure, and primary damper position with downstream static pressure maintained at 0.25 in. w.g. (62.2 Pa).

Models describing airflow and fan power consumption as functions of inlet static pressure and voltage were developed. This paper presented an example of an experimental setup adhering to AHRI standard 880 highlighting the prevalence of the stated assumption relating to downstream pressure loss.

In-Situ fan differential pressure rise for a series VAV-fan-powered terminal unit with SCR control

The relationship between system airflow and observed differential pressure rise across a series terminal unit was studied as part of an AHRI research project (Bryant and Bryant, 2015) The experimental setup adhered to AHRI 880. They observed that for a range of system airflows the differential pressure rise across the terminal unit was within a range of 0.13 – 0.27 in w.g. (32.4 – 67.3 Pa). Findings from this study have subsequently been verified in testing at several manufacturer's laboratories. These findings

support a more representative estimate when terminal units are modeled in simulation programs such as EnergyPlus (DOE).

Characterizing airflow and power of VAV series fan-powered terminal unit from component data

In 2014, experiments were conducted on a set of eight series type terminal units that had been obtained from three different manufacturers, four of which were 8 in. (200 mm) units with the remainder being 12 in. (300 mm) units (Yin and O’Neal, 2014a). Models describing FPTU performance were developed based on individual component models. Part I developed models for terminal power and airflow while Part II developed primary and plenum airflow models based on testing unit dampers and housing.

In Part I the experimenters varied the fan speeds (as a fraction of maximum motor performance), downstream discharge static (0.1 – 0.65 in. w.g. (24.9 – 161.9 Pa)), and recorded airflow and FPTU fan power data. Models were developed for fan airflow and power. Further, fan efficiency was presented as a function of airflow and it was observed to be in a range of 11% to 50% for total fan/motor efficiency and static efficiency ranging from 1% to 22%.

The empirical models developed in Part I did not rely on AHRI standard 880, however, the power model which was a function of downstream static pressure was developed with AHRI 880 conditions. In Part II empirical models were developed describing primary air flow as a function of pressure differential across the fan and primary damper position, while plenum airflow was modeled as a function differential pressure and terminal inlet size.

Energy use comparison for series vs. parallel fan-powered terminal units in a single duct variable air volume system

An energy model comparing series vs. parallel FPTU power consumption and based on estimated parallel FPTU leakage inputs as a function of total primary flow for the parallel terminal unit was developed in a 2010 study (Bryant et al, 2010). The model ran six iterations,

1. Control run
2. 10% Leakage for parallel unit

3. 20% Leakage for parallel unit
4. Simulate different unit manufacturer data
5. “Zero Power” terminal fan power consumption was neglected
6. Return air heat gain case

Under all conditions except the third run, the parallel FPTU system consumed less power. However, when parallel FPTU leakage of 20% or more was included in the model, series FPTU’s begin to outperform their parallel counterparts highlighting the need to further study and model the leakage observed in parallel FPTU’s.

Problem Statement for Current Study

1. Under existing energy modeling tools, which of the two variables (FPTU efficiency or static pressure rise) plays the larger role in impact on results?
2. Is there evidence to indicate that FPTUs (parallel or series) leak under as-built (installed) conditions?
3. Is the conventional design parameter of 0.25” w.g. (62.21 Pa) downstream static pressure representative of VAV FPTUs installed in actual field installations?
4. Are the results for a series FPTU static pressure rise obtained by Bryant and Bryant, 2015 similar to “real world” FPTU installations?

Research Objectives

1. Establish an experiment scheme that provides measurement of static pressure downstream of the FPTU and static pressure rise across the FPTU fan for a given primary air flow
2. Collect data on a population of VAV FPTU’s that is considered representative of current market availability
3. Compile an energy simulation using in-situ data to highlight major factors affecting energy consumption of the FPTU
4. Qualitatively describe the performance of series vs parallel FPTU with respect to a measure of terminal leakage

Limitations

The proposed study will use FPTU installations as found on the main campus of Texas A&M University located in College Station, Texas. This introduces certain limitations based on site availability and accessibility;

- Terminal unit manufacturer and size
- Installation date and unit age
- Assumes FPTU and VAV system is operating per design
- On site above ceiling accessibility and space available

In Situ Measurement Methodology

Data was collected from installed series type FPTU's selected from building locations across the Texas A&M campus at College Station, Texas. Figure 1.4 is a schematic showing the proposed experimental setup and sensor location. Table 1.1 also shows the data collected from the on campus Building Management System (BMS).

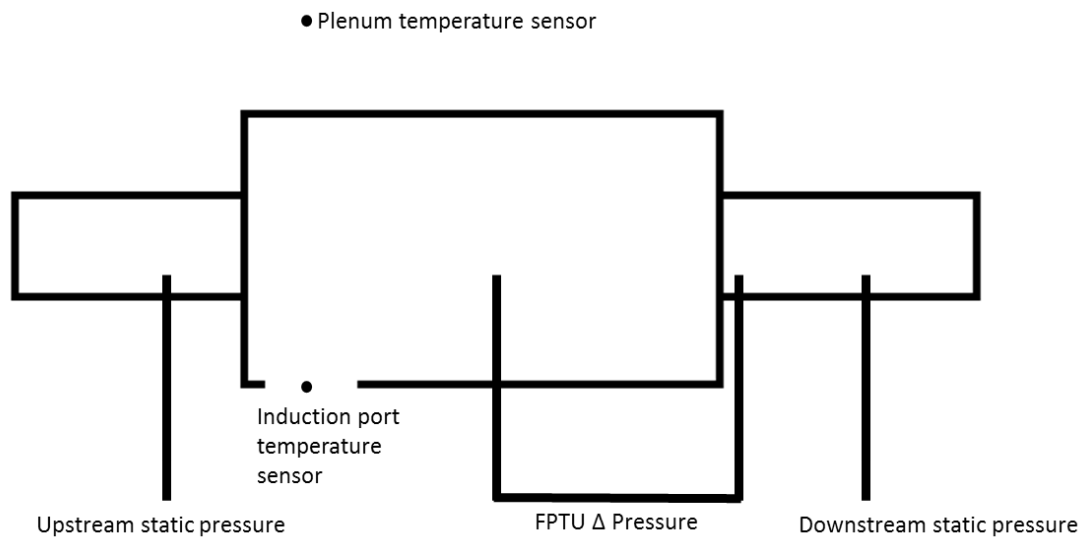


Figure 1.4. Proposed experimental setup

Table 1.1. Summary of data points to be measured

Data Point	Measurement Method
Primary airflow	BMS
Primary volume damper position	BMS
Secondary discharge air temperature	BMS
Upstream pressure	Differential Pressure Transducer – ONSET T-VER-PXU-L
Differential pressure across the terminal unit	Differential Pressure Transducer – ONSET T-VER-PXU-L
Downstream pressure	Differential Pressure Transducer – ONSET T-VER-PXU-L
Plenum temperature	2 X Temperature Sensors – ONSET S-TMB-M006
Data logger	ONSET U30 Data Logger

An infrared (IR) camera (Flir i7) was also used to photograph a set of FPTU's. The IR images were used to identify specific discrete locations of a temperature difference suggesting air leakage.

Energy Simulation Methodology

The energy simulation compiled by Dr. Dennis O'Neal and Dr. Peng Yin was a representation of a single floor five zone conditioned space with four perimeter zones and a central zone (fig. 1.5),

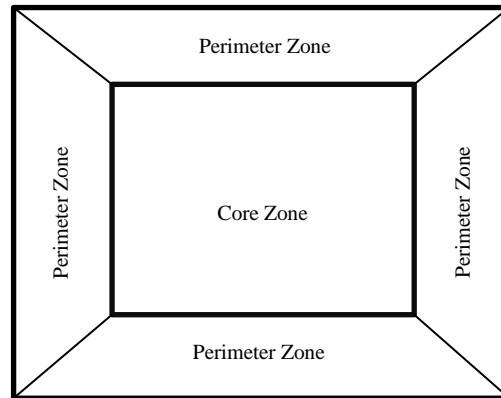


Figure 1.5. Energy model zones

The zones are served by series permanent split capacitor (PSC) FPTU's and a central VAV air handler. The air handler component contains a chilled water cooling coil connected to a water-cooled chiller while the FPTU's components contain water loop reheat coils connected to a natural gas boiler.

Construction materials, occupancy, lighting and equipment loads, schedules and weather data (San Francisco, CA) were held constant throughout the simulations. The only alterations were made to the

FPTU's fan efficiencies and static pressure rise. The fan/motor efficiency was varied from 20% to 40% in 10% increments while including a 70% efficiency input. Static pressure rise was varied from 0.5 in. w.g. (124 Pa) to 3.5 in. w.g. (871 Pa) in 0.5 in. w.g. increments. The simulation was carried out with every possible combination of fan/motor efficiency and FPTU static pressure rise.

CHAPTER II

ENERGY SIMULATION

The energy simulation described in chapter one (energy simulation methodology) was run with the purpose of identifying which of the two main EnergyPlus inputs (fan/motor efficiency and FPTU static pressure rise) contributed to an observable change in the total power consumed by the simulated building. The fan/motor efficiency was varied from 20% to 40% in 10% increments while including a 70% efficiency input while FPTU static pressure rise was varied from 0.5 in. w.g. (124 Pa) to 3.5 in. w.g. (871 Pa) in 0.5 in. w.g. increments.

Figure 2.1 highlights the relationship between electrical energy consumed by the FPTU's (along with the central air handler) with variable FPTU total pressure rise through a range of efficiencies.

The figure highlights that at low fan static pressure, the energy consumption varies from 8,000 kWh (at 0.5 in w.g. (124.5 Pa) and 20%) to 2,900 kWh (at 0.5 in w.g. (124.5 Pa) and 70%) annual consumption, a decrease of 64%. At high fan static pressure, energy consumption varies from 52,300 kWh (at 3.5 in w.g. (871.8 Pa) and 20%) to 15,400 kWh (at 3.5 in w.g. (871.8 Pa) and 70%) annual consumption, a decrease of 71%. A more efficient fan (higher than 40%) uses less energy for a given fan pressure. Conversely, a low efficiency fan shows considerable change in energy consumption over the range of fan pressure rise.

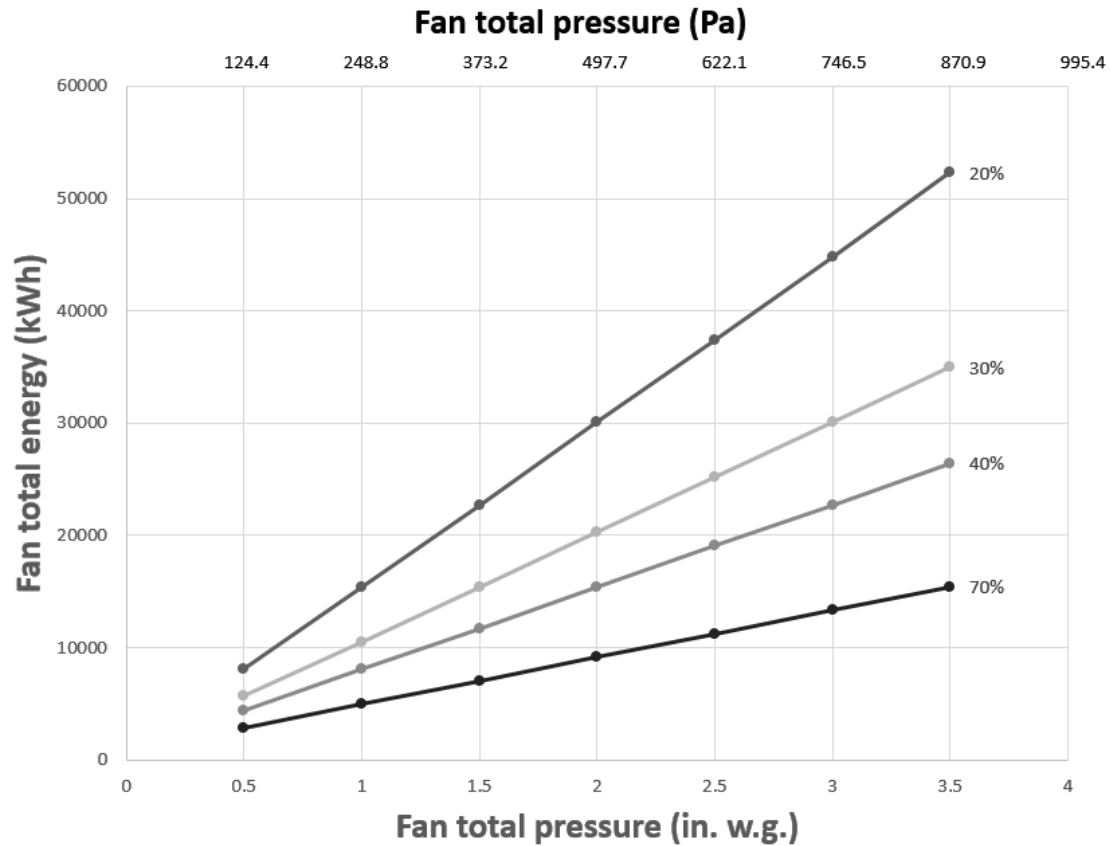


Figure 2.1. Total energy consumed by FPTU's

If a very low efficiency fan is specified in the energy simulation, there is an observable impact on the supplemental heating energy required. Figure 2.2 shows this relationship for the combinations used in the EnergyPlus simulation. The simulation results converge at the 0.5 in. w.g. (124 Pa) point regardless of efficiency at around 22,000 kWh of heating needed to satisfy zone requirements. As fan differential pressure is increased however, the model shows that additional heating needs are reduced. The simulation is calculating the additional heat that would be generated by the electric fan motor and adds that to the airstream. This is “free” heat, though gained at the expense of an inefficient electric motor or requiring a very high static pressure from the fan. The combination of high static and low efficiency produces the most “free” heat and the simulation shows virtually no additional heating energy is required.

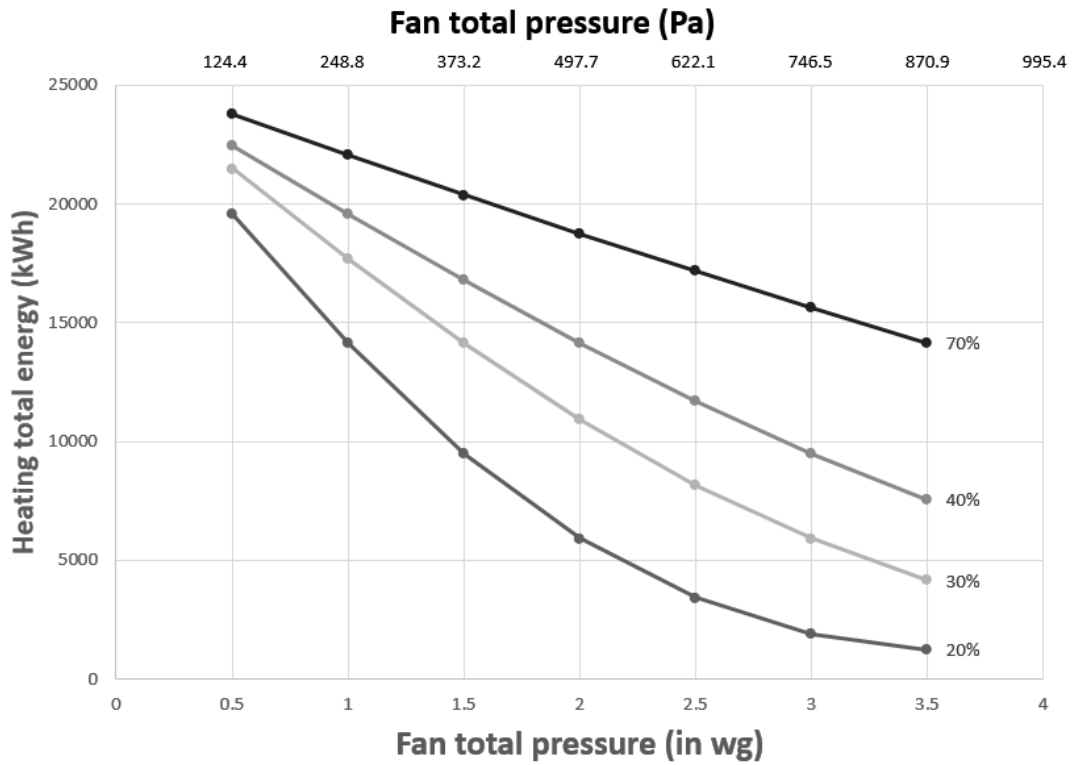


Figure 2.2. Total heating energy

Figure 2.3 presents the total energy consumed by the HVAC system. Despite the large differences in FPTU energy consumption for fan and heating, when total HVAC energy is considered the difference is minimal. Maximum differences of 2.3% were noted at the extremes of 3.5 in. w.g. (872 Pa) at 20% efficiency and 0.5 in. w.g. (124 Pa) at 70% efficiency.

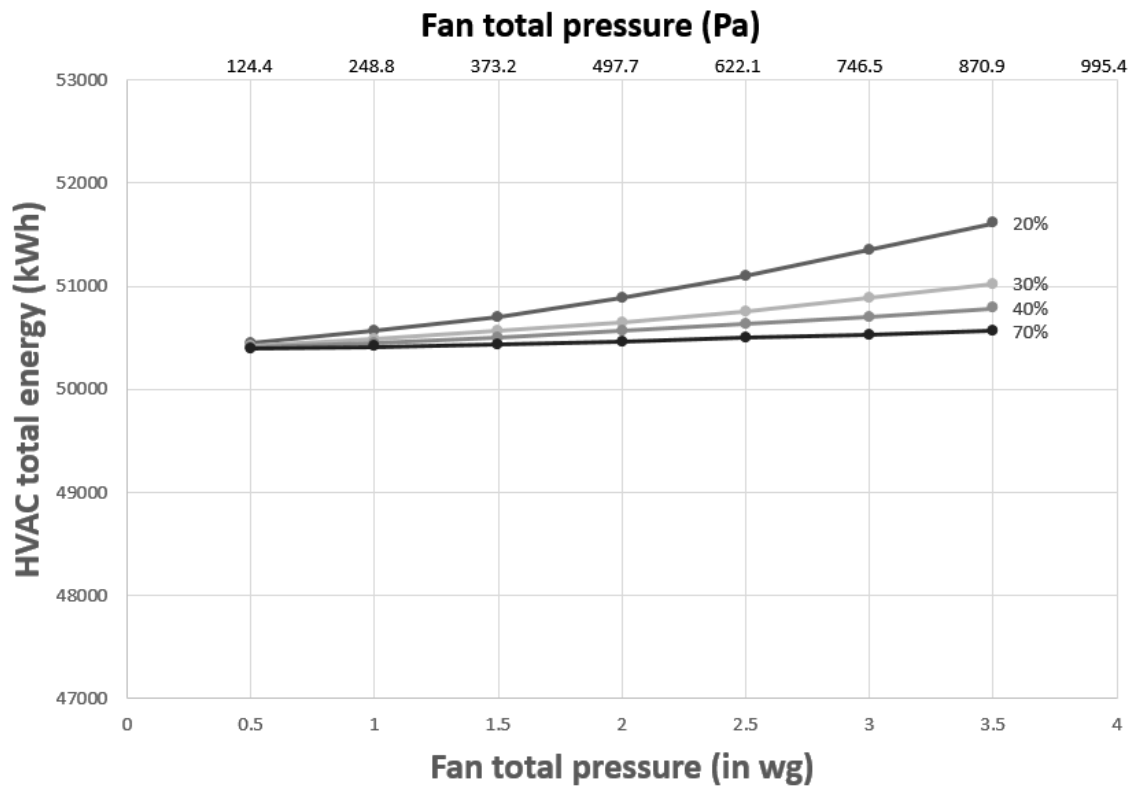


Figure 2.3. Total energy consumed by modeled HVAC system

Discussion

From the results of the EnergyPlus simulations it was found that for series PSC FPTUs, decreasing efficiency and increasing the FPTU static pressure value would result in a marked increase in FPTU fan electrical energy consumption.

At low FPTU fan efficiency, increasing the FPTU static pressure would result in a decrease in heating energy requirements. The EnergyPlus model accounts for the energy lost through fan motor inefficiency in the FPTU as heat into the conditioned zone resulting in lower heating requirements from primary heating (hot water or electrical heating) HVAC system components.

FPTU efficiency plays a reduced role in determining energy consumption when a FPTU static pressure is selected less than 1.0 in. w.g. (249 Pa) or more appropriately 0.25 in. w.g. (62.2 Pa) (Bryant

and Bryant 2015). In cases where FPTU fan static pressures are greater than 1.0 in. w.g. (249 Pa) the selection of an appropriate fan/motor efficiency (Yin and O'Neal 2014a) becomes more critical.

However, even with the large impacts on FPTU fan energy and FPTU supplemental heating with changes in fan static pressure and efficiency, total HVAC system energy is remarkably unaffected. This was clearly shown in the simulation results of Figure 2.2.

CHAPTER III

EVIDENCE OF LEAKAGE FOR SERIES AND PARALLEL FPTU'S

As stated in chapter one, two experiments were conducted to qualitatively determine any evidence of leakage for series and parallel FPTU's. The first experiment logged the ambient plenum air temperature and the air temperature of the FPTU induction port. An observable difference in temperatures was considered an indicator of air leakage.

The second experiment involved observing various FPTU's operating under 100% primary air flow conditions through an infrared camera. Any observed temperature fluctuations was considered as evidence of leakage.

Evidence of Leakage Through Observed Temperature Differences

In order to qualitatively identify leakage in FPTU's the difference between induction port and plenum temperature readings were compared using the paired t-test where the null hypothesis states that the difference between induction port and plenum mean temperatures does not exceed 1.0°F, which is the lowest level of accuracy conventional thermostats respond to.

$$H_0: \mu_{induction\ port} - \mu_{Plenum} < |1.0|$$

$$H_A: \mu_{induction\ port} - \mu_{Plenum} > |1.0|$$

These tests were conducted at a 90% confidence interval.

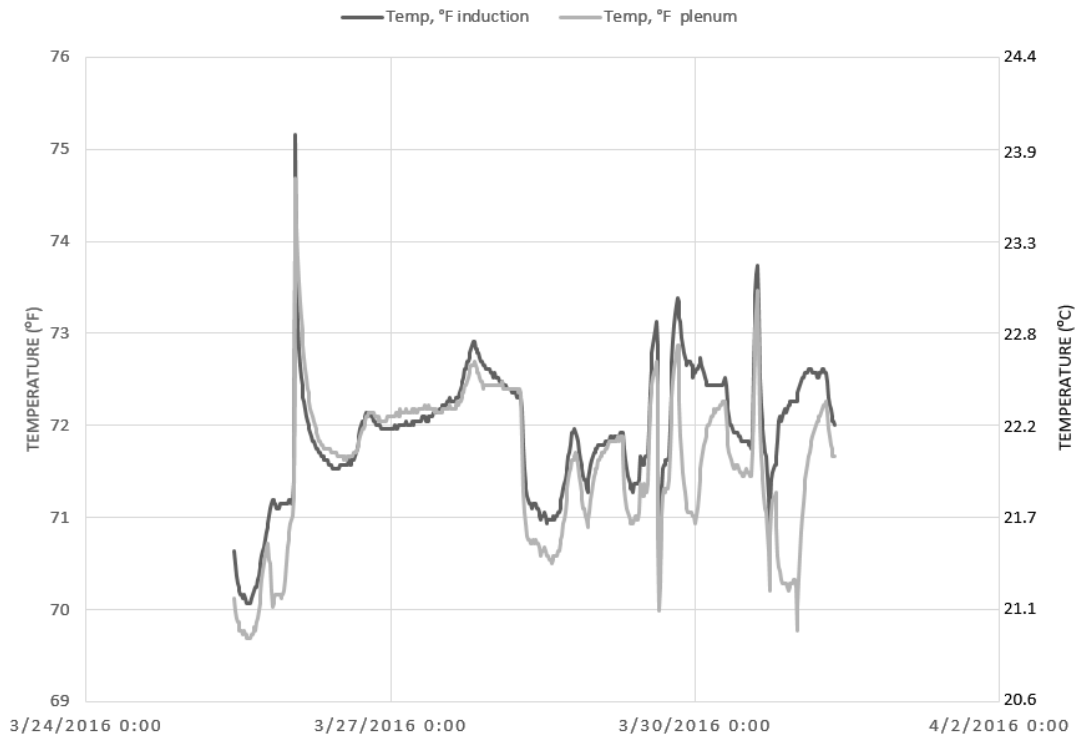


Figure 3.1. TAMU Agrilife Extension Services Building (AGLS), Rm 129 (series FPTU) – temperature data

Mean plenum temperature = 71.6 °F

Mean induction port temperature = 71.9 °F

Mean Difference = 0.334 °F

Lower 90% = 0.2996 °F

Upper 90% = 0.3684 °F

Standard error = 0.02087

N = 569

The confidence interval does not satisfy the alternate hypothesis, the null hypothesis is therefore not rejected. There was no significant evidence of a temperature difference between the two sensors.

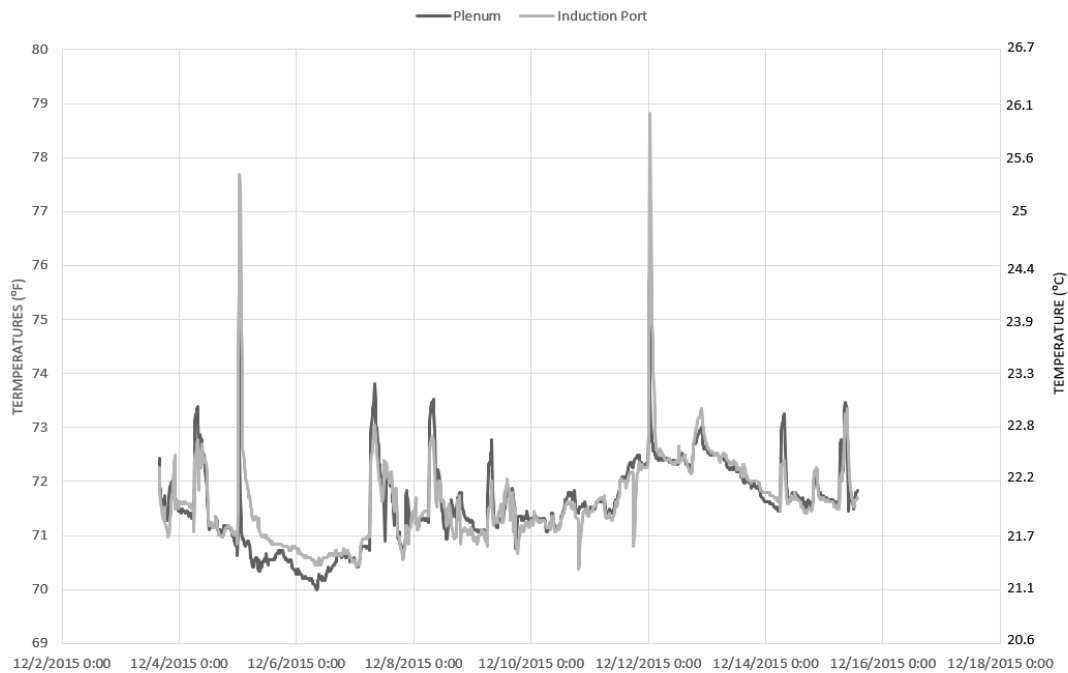


Figure 3.2. TAMU Agrilife Extension Services Building (AGLS), Rm 132 (series FPTU) – temperature data

Mean plenum temperature = 71.7 °F

Mean induction port temperature = 71.6 °F

Mean Difference = 0.05332 °F

Lower 90% = 0.01493 °F

Upper 90% = 0.0779 °F

Standard error = 0.01493

N = 1144

The confidence interval does not satisfy the alternate hypothesis, the null hypothesis is therefore not rejected. There was no significant evidence of a temperature difference between the two sensors.

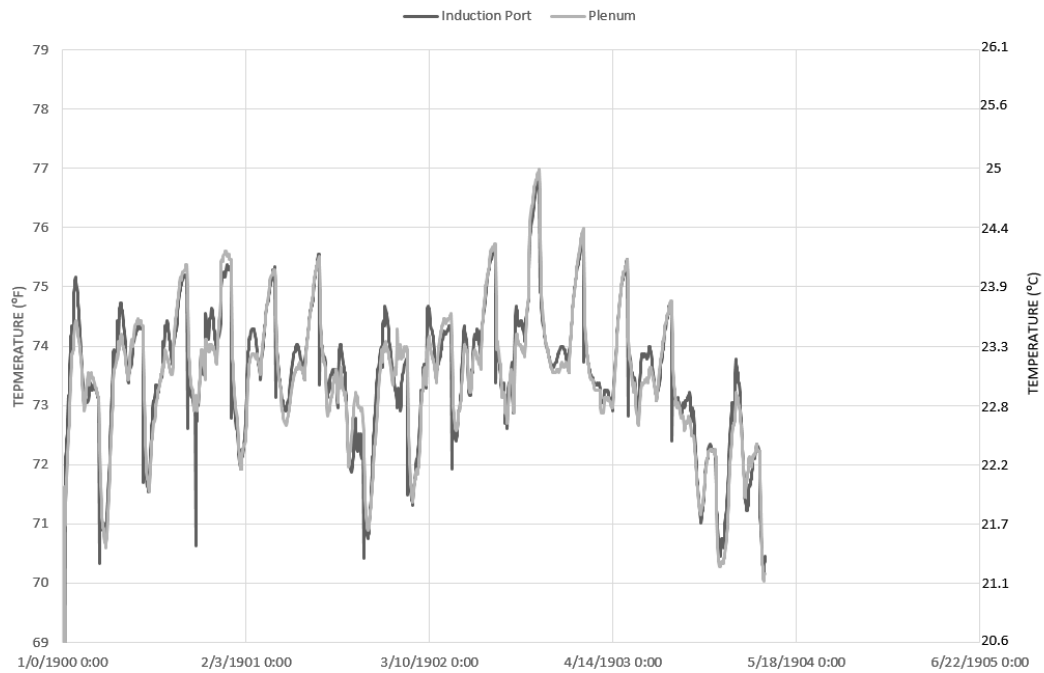


Figure 3.3. TAMU Institute of Preclinical Studies (TIPS), Rm 2043 (series FPTU) – temperature data

Mean plenum temperature = 73.5 °F

Mean induction port temperature = 73.5 °F

Mean Difference = 0.0482 °F

Lower 90% = 0.0332 °F

Upper 90% = 0.0632 °F

Standard error = 0.00912

N = 1528

The confidence interval does not satisfy the alternate hypothesis, the null hypothesis is therefore not rejected. There was no significant evidence of a temperature difference between the two sensors.

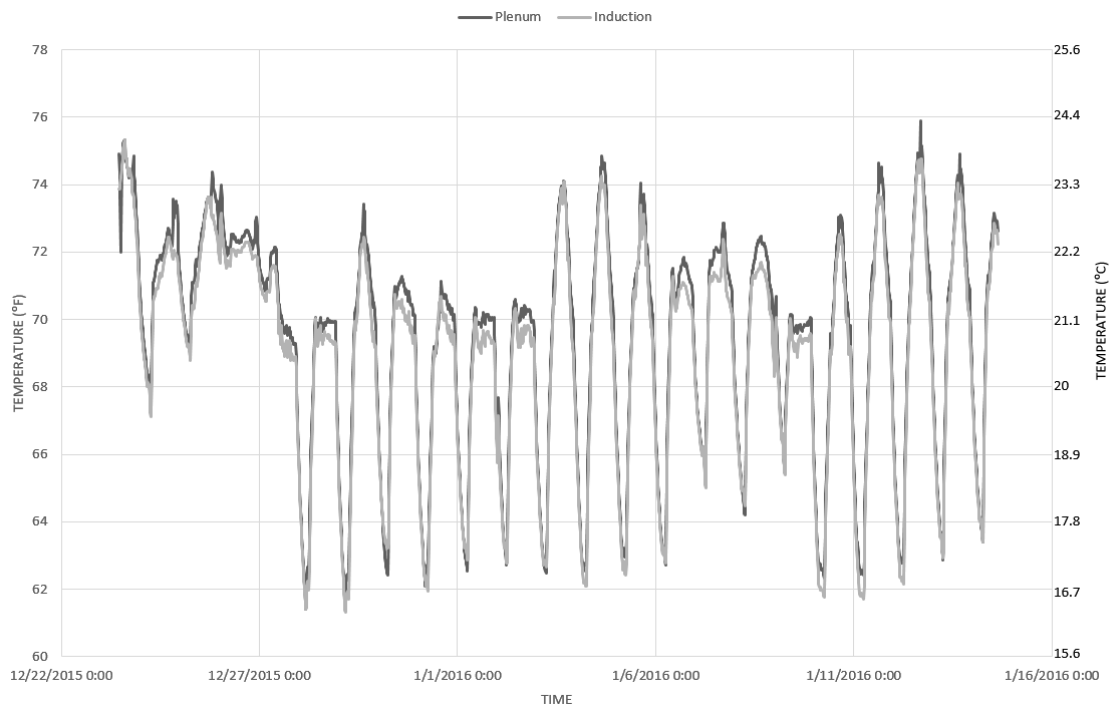


Figure 3.4. TAMU Institute of Preclinical Studies (TIPS), auditorium (parallel FPTU) – temperature data

Mean plenum temperature = 69.4 °F

Mean induction port temperature = 69.0 °F

Mean Difference = 0.4428 °F

Lower 90% = 0.4324 °F

Upper 90% = 0.4533 °F

Standard error = 0.00635

N = 2129

The confidence interval does not satisfy the alternate hypothesis, the null hypothesis is therefore not rejected. There was no significant evidence of a temperature difference between the two sensors.

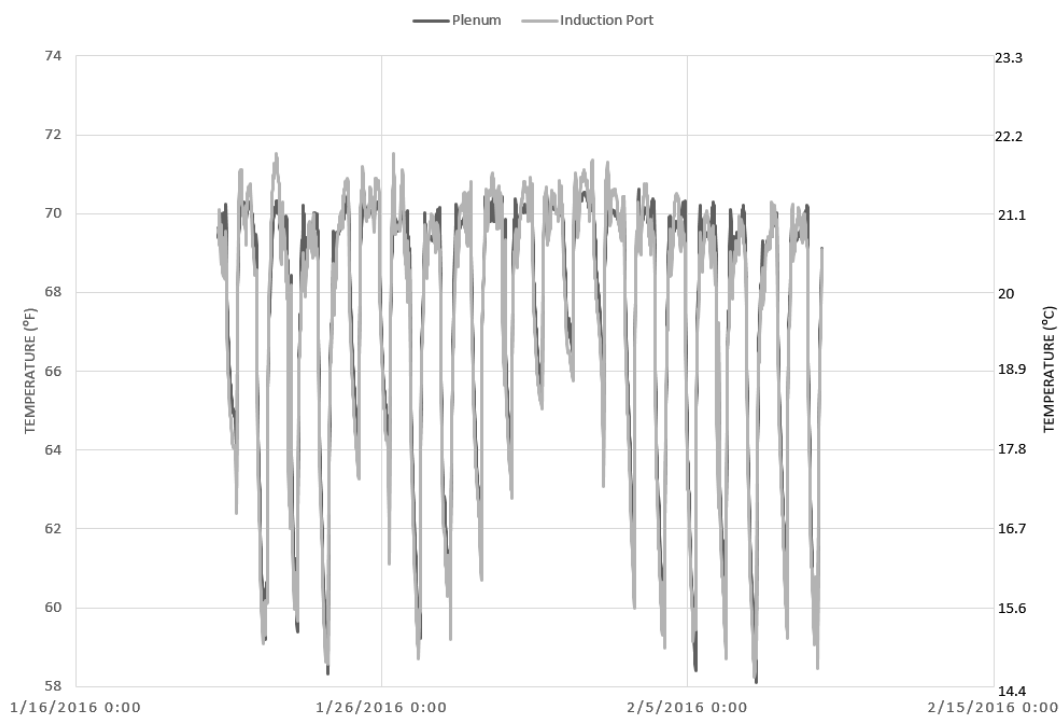


Figure 3.5. TAMU Institute of Preclinical Studies (TIPS), Conf. Rm B (series FPTU) – temperature data

Mean plenum temperature = 67.5 °F

Mean induction port temperature = 67.3 °F

Mean Difference = 0.231 °F

Lower 90% = 0.2094 °F

Upper 90% = 0.2525 °F

Standard error = 0.01309

N = 1895

The confidence interval does not satisfy the alternate hypothesis, the null hypothesis is therefore not rejected. There was no significant evidence of a temperature difference between the two sensors.

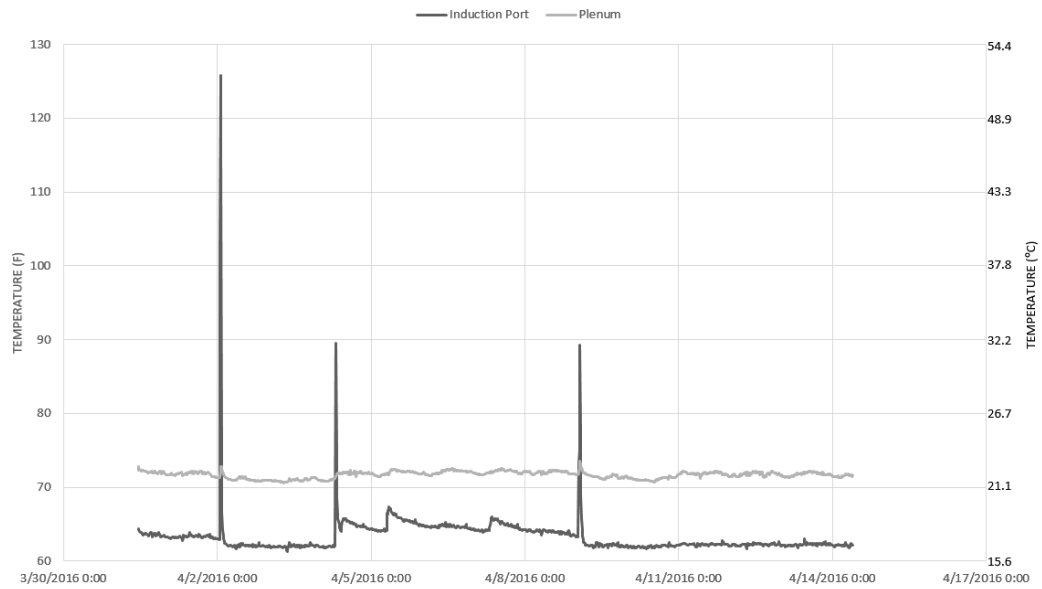


Figure 3.6. TAMU Transportation Institute (TTI), entrance lobby (parallel FPTU) – temperature data

Mean plenum temperature = 71.7 °F

Mean induction port temperature = 63.3 °F

Mean Difference = 8.32397 °F

Lower 90% = 8.19225 °F.

Upper 90% = 8.45569 °F

Standard error = 0.08002

N = 1339

The confidence interval satisfies the alternate hypothesis, the null hypothesis is therefore rejected. The data suggests that there is evidence of a temperature difference between the plenum space and induction port indicating that the FPTU in question is leaking air through the induction port into the plenum.

Evidence of Leakage Through Infrared Observations

Figures 3.7, 3.8, and 3.9 are digital and infrared images taken of in-situ FPTUs at Texas A&M University. These images show what portions of the FPTU looked like (digital) and what the infrared image indicated about the relative temperature differences between the field of view of the infrared and the surrounding environment. All observed FPTU's were operated at full primary air flow conditions insuring the units were under positive pressure.

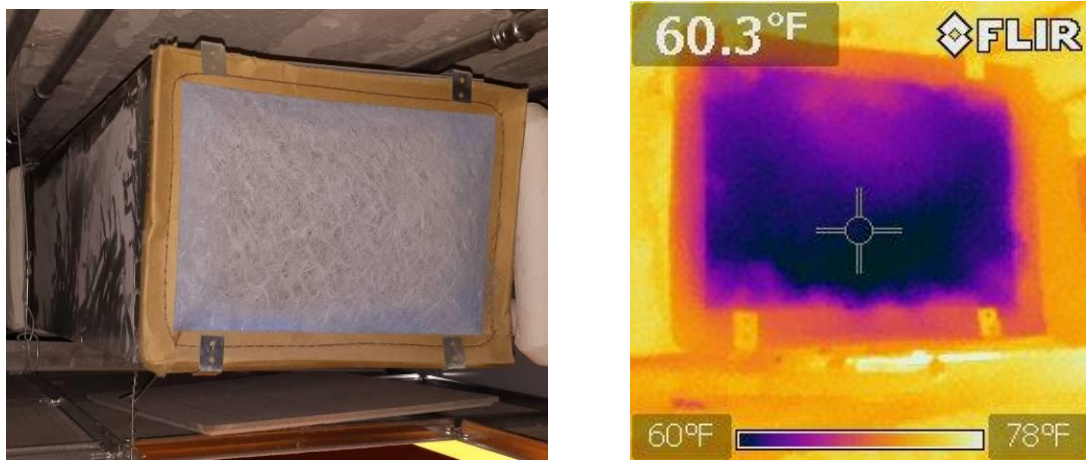


Figure 3.7. Induction port of a parallel FPTU

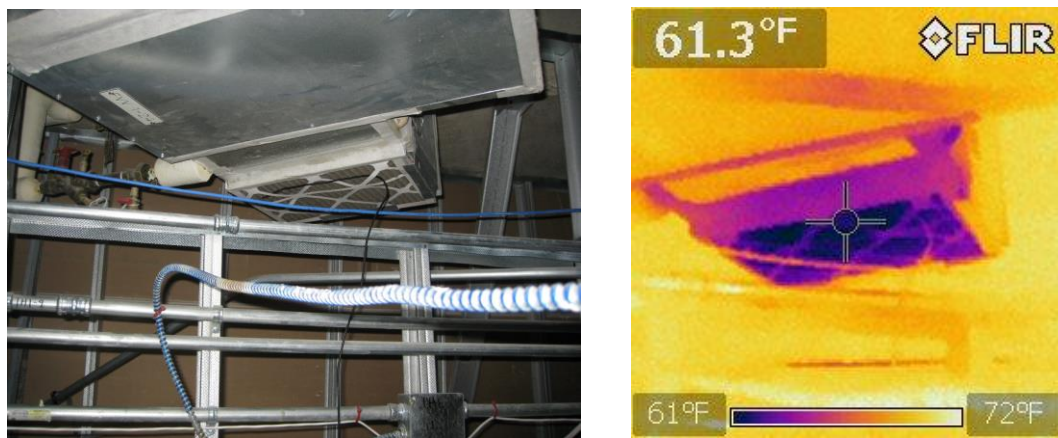


Figure 3.8. Plenum and induction port temperature images for parallel FPTU

Figure 3.7 and 3.8 show the temperature differences between the plenum space and the respective parallel FPTU induction ports. Figure 3.7 shows that the lowest temperature in the image field was within the induction port space at 60.3°F (15.7°C). Figure 3.8 shows the lowest temperature of 61.3°F (16.3°F) in that image was also at the induction port of the FPTU. These temperature differences seem to indicate that cold primary air was leaking from the parallel FPTU and out into the surrounding plenum.

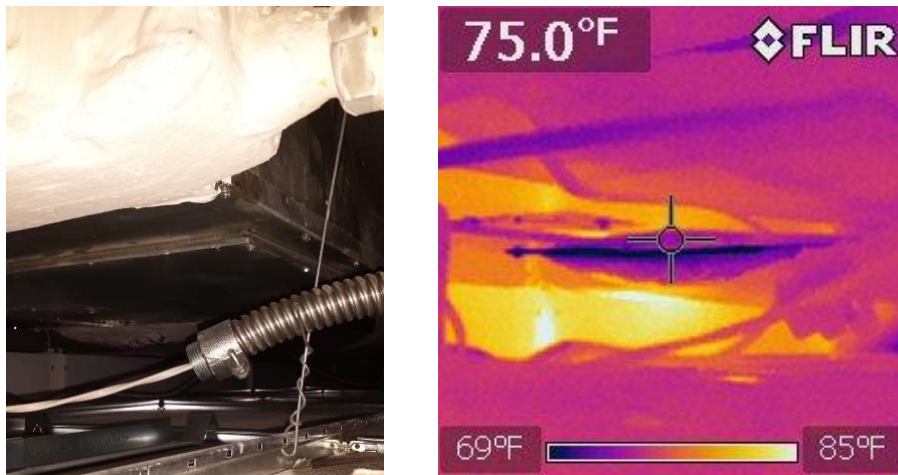


Figure 3.9. Access panel seam leakage in a parallel FPTU

Figure 3.9 is an infrared image of a parallel FPTU highlighting the relatively lower temperatures around the unit's seams, another possible indication of air leakage.



Figure 3.10. Construction Seam Leakage for a Series FPTU

Figure 3.10 is of a series FPTU in over-pressure conditions indicating possible leakage through the seams. During field measurements on this unit, the FPTU was found to be malfunctioning and was operating under much higher than normal pressure. These operating conditions, though not usual for series FPTU, show that leakage can occur in these units as well.

Discussion

Based on the temperature data recorded at the FPTU induction port and plenum area, and the statistical analysis performed on the data, there is no significant statistical support for the evidence of air leakage from the induction port of series FPTU's.

For the parallel FPTU's that were observed in this study however, there are mixed results. Data collected from the TAMU Institute of preclinical studies (TIPS) auditorium FPTU suggest no evidence for air leakage while data collected for TAMU Transportation institute (TTI) entrance FPTU suggest significant evidence of air leakage.

Although the data from the TIPS Auditorium FPTU suggested no leakage it is worth noting that this FPTU was observed during a very low occupancy and usage period (winter break). The FPTU was operating under a program with a setback that allowed the zone to cool to a much lower temperature in order to reduce energy usage. This type of control was implemented across most of the Texas A&M campus as a matter of operation during the semester (winter) break.

Data collected from only two parallel FPTU's is not a representative sample size of the population of installed parallel FPTU's. Several uncontrollable factors had direct impact on access to FPTUs. There were difficulties in access to buildings (security, classes), access to an FPTU (units located above furniture/lab equipment), and adequate room above the ceiling to install metering equipment. The large plenum/induction port temperature difference observed in the TTI Entrance FPTU supports results from the Energy Systems Laboratory project (ASHRAE RP-1292) for parallel FPTU leakage problems. However, the lack of consistency in the results does call for further study on in-situ leakage for parallel FPTU's.

CHAPTER IV

DOWNSTREAM STATIC PRESSURE READINGS FOR FPTU'S

Downstream static pressure data for six FPTU's was collected, including four series FPTU's and two Parallel FPTU's. Data from these units was recorded with a differential pressure transducer in parallel with the temperature measurements for the FPTU.

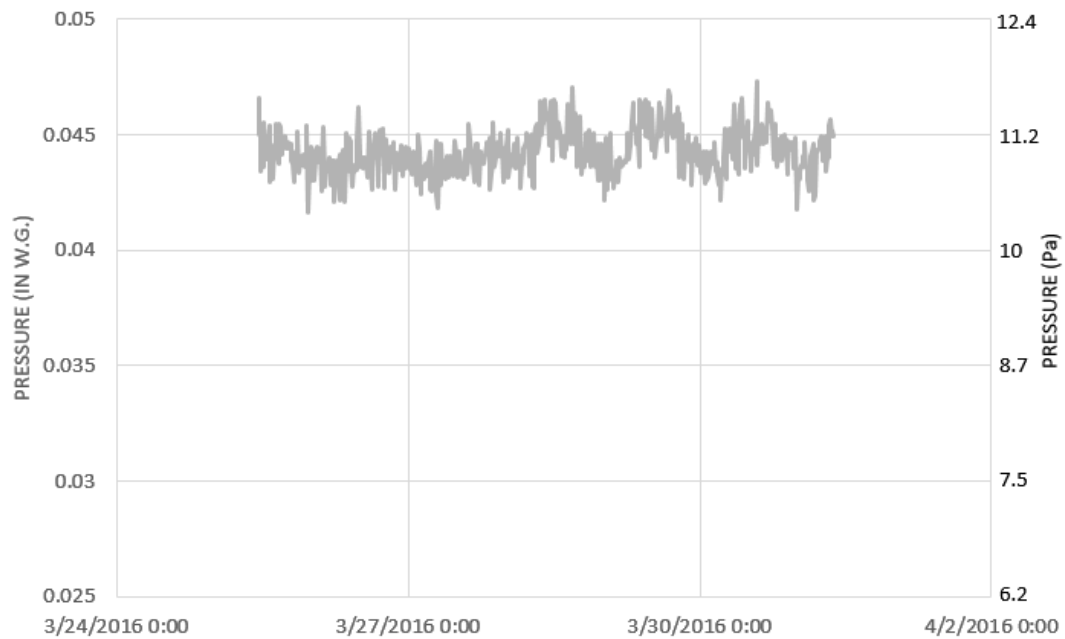


Figure 4.1. TAMU Agrilife Extension Building (AGLS), Rm 129 (series FPTU) – downstream static pressure

Figure 4.1 shows the pressure data collected downstream of the FPTU over a seven-day period. The FPTU operated between 0.0417 in. w.g. (10.4 Pa) and 0.0473 in. w.g. (11.7 Pa) with a mean downstream static pressure of 0.0442 in. w.g. (11 Pa)

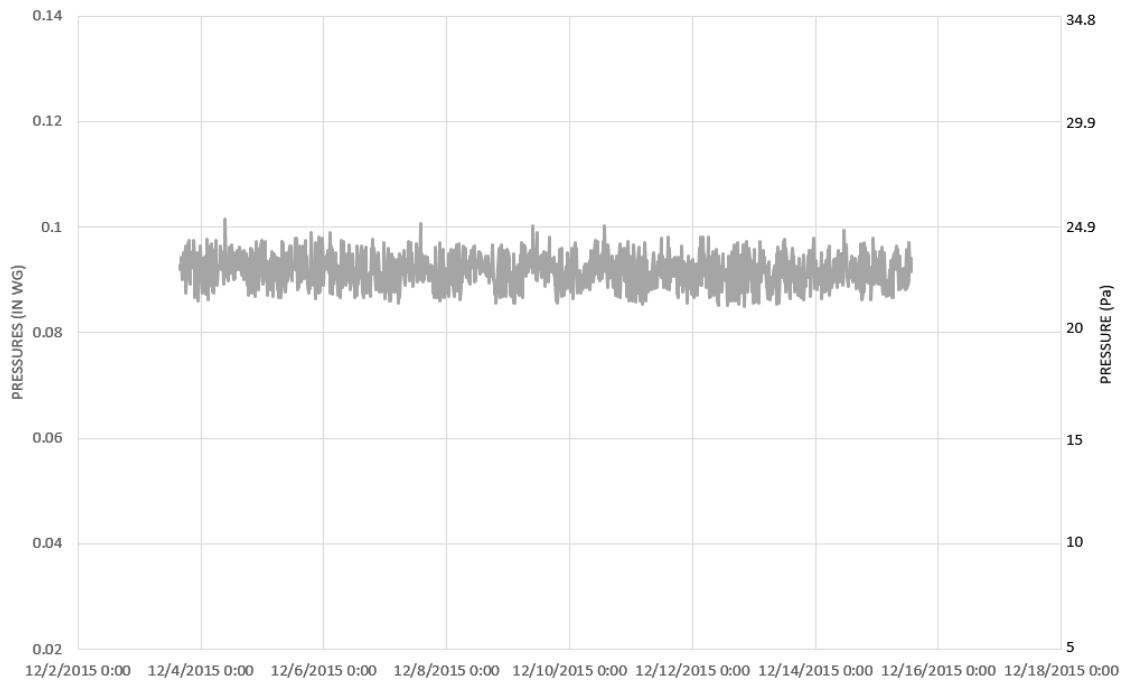


Figure 4.2. TAMU Agrilife Extension Building (AGLS), Rm 132 (series FPTU) – downstream static pressure

Figure 4.2 shows pressure data that were collected downstream of the FPTU over a 12-day period. The FPTU operated between 0.0849 in. w.g. (21.1 Pa) and 0.1014 in. w.g. (25.2 Pa) with a mean downstream static pressure of 0.0917 in. w.g. (22.8 Pa).

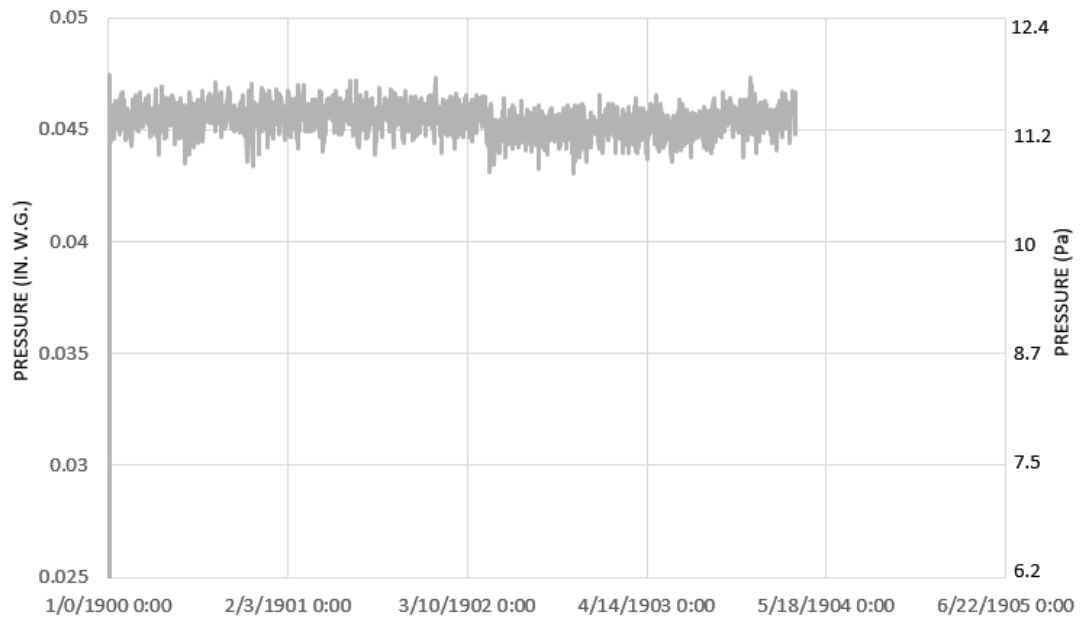


Figure 4.3 TAMU Institute of Preclinical Studies (TIPS), Rm 2043 (series FPTU) – downstream static pressure

Figure 4.3 shows pressure data that were collected downstream of the FPTU over a 17-day period. The FPTU operated between 0.0430 in. w.g. (10.7 Pa) and 0.0473 in. w.g. (11.7 Pa) with a mean downstream static pressure of 0.0454 in. w.g. (11.3 Pa).

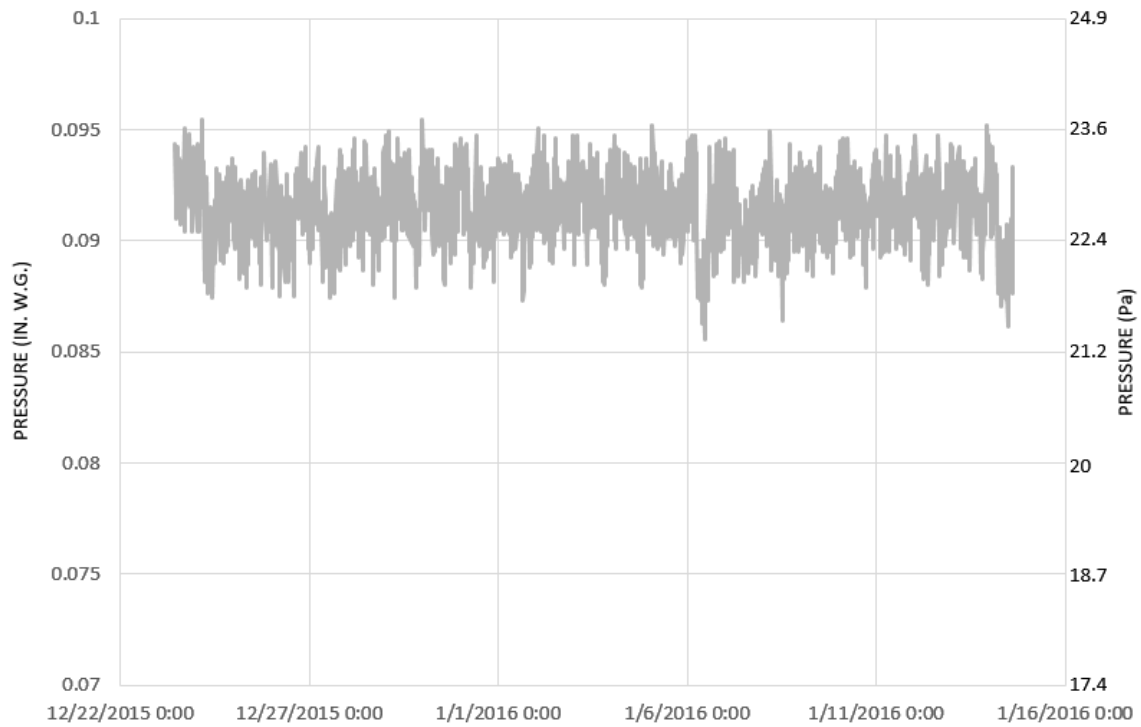


Figure 4.4 TAMU Institute of Preclinical Studies (TIPS), auditorium (parallel FPTU) – downstream static pressure

Figure 4.4 shows the pressure data collected downstream of the FPTU over a 23-day period. The FPTU operated between 0.0855 in. w.g. (21.3 Pa) and 0.0955 in. w.g. (23.8 Pa) with a mean downstream static pressure of 0.0915 in. w.g. (22.8 Pa).

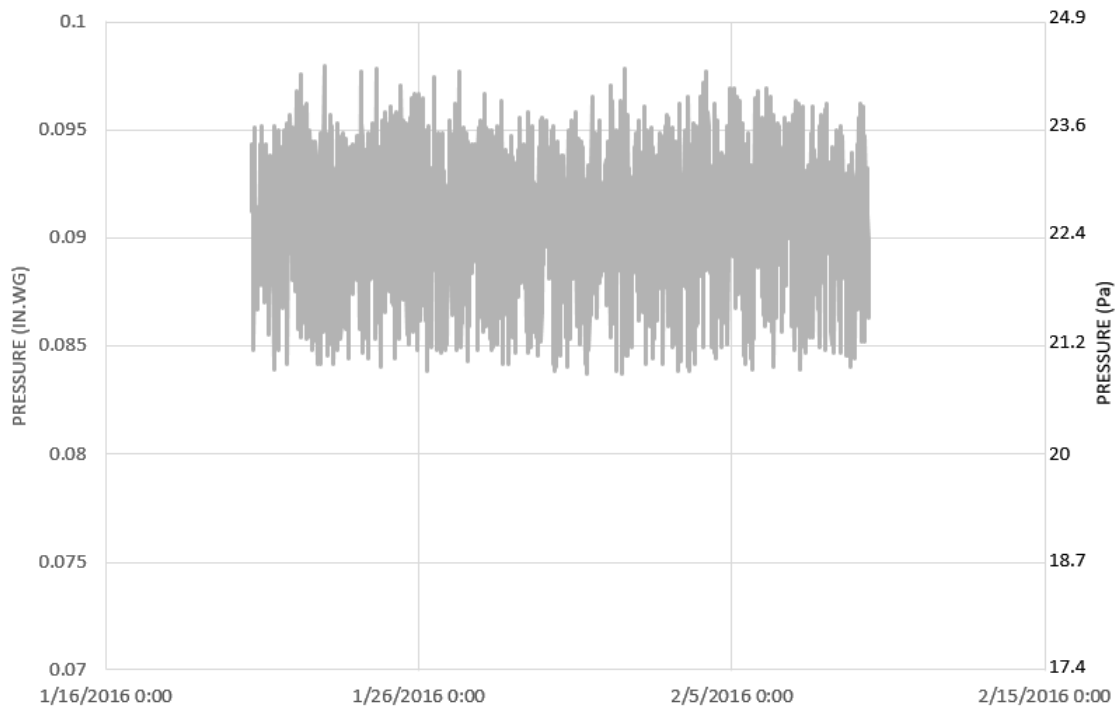


Figure 4.5 TAMU Institute of Preclinical Studies (TIPS), Conf. Rm B (series FPTU) – downstream static pressure

Figure 4.5 presents the pressure data collected downstream of the FPTU over a 20-day period. The FPTU operated between 0.0837 in. w.g. (20.8 Pa) and 0.0979 in. w.g. (24.4 Pa) with a mean downstream static pressure of 0.0908 in. w.g. (22.6 Pa).

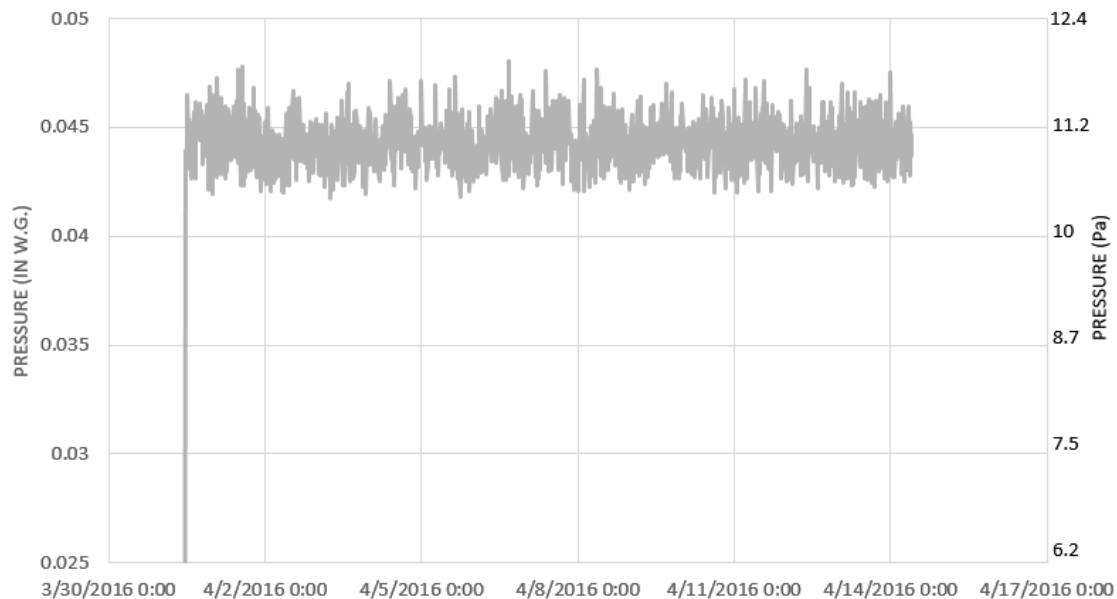


Figure 4.6 TAMU Transportation Institute (TTI), entrance lobby (parallel FPTU) – downstream static pressure

Figure 4.6 presents the pressure data collected downstream of the FPTU over a 15-day period. The FPTU operated between 0.0417 in. w.g. (10.4 Pa) and 0.0480 in. w.g. (11.9 Pa) with a mean downstream static pressure of 0.0443 in. w.g. (11 Pa).

Discussion

In-situ measurements of downstream static pressures for a selection of series and parallel FPTU's were found to range between 0.0417 and 0.1014 in. w.g. (10.4 Pa – 25.3 Pa) with little variation in the measurements observed for individual FPTUs. All the FPTU were observed over at least a two-week period to allow for complete cycling of normal, weekend, and evening operations. This provided opportunity for “normal” operation to be established.

The data suggests that the conditions set by ANSI/AHRI 880 section 7.2.1.2 which requires FPTU's be tested and rated at a downstream static pressure of 0.25 in. w.g. (62.2 Pa) are not representative of “real-world” FPTU installation and operation conditions. The discrepancy between the observed data and the conditions set by ANSI/AHRI 880 raise the question of “oversizing” FPTU's. Selecting an FPTU

with a higher static pressure than the observed downstream conditions (due to duct routing and air terminal positions) will result in the fan delivering greater than desired airflow to the zone being served.

CHAPTER V

OBSERVED PRESSURE RISE ACROSS SERIES FPTU

The pressure rise across a single FPTU was observed and logged using a pressure transducer over a period, while a similar pressure reading was taken and recorded with a hand held micromanometer for two additional FPTUs. In figure 5.1 the FPTU static pressure differential was observed between 0.21 in. w.g. and 0.25 in. w.g. with a mean pressure difference of 0.21. in w.g.

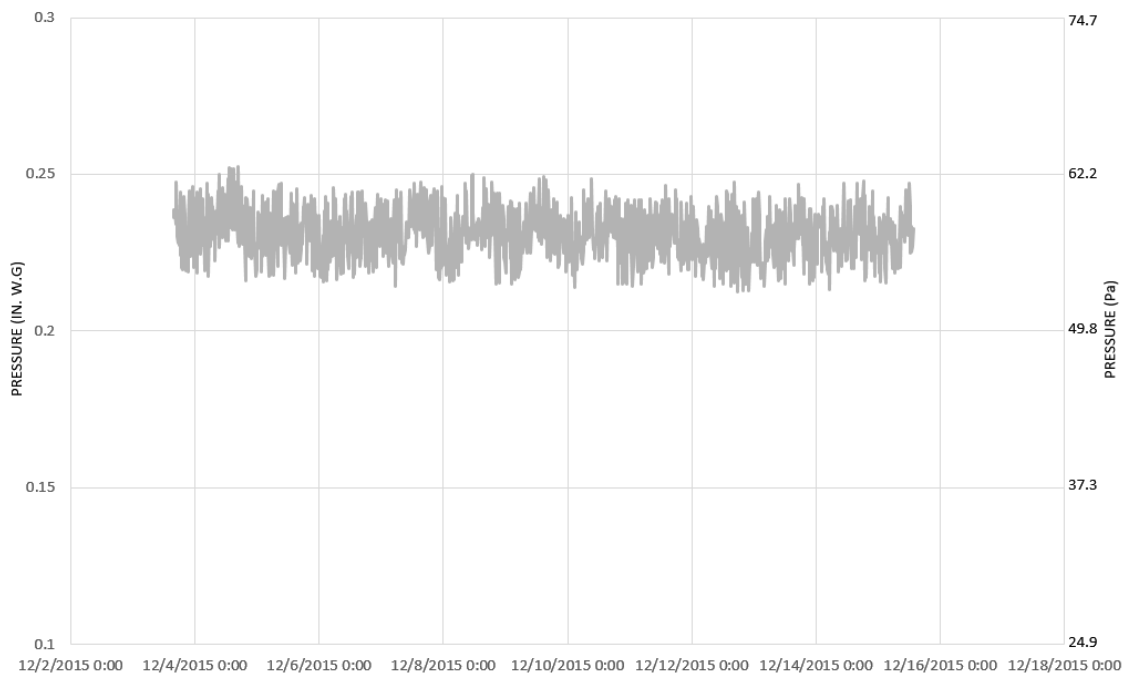


Figure 5.1. TAMU Agrilife Extension Building (AGLS), Rm 132

The micromanometer was used to measure the pressure difference across two additional series FPTU's. In the TAMU Institute of Preclinical Studies (TIPS), Conference Room B the static pressure difference was measured at 0.22 in w.g. (54.8 Pa). While the FPTU in room 2043 static pressure difference was measured at 0.23 in w.g. (57.3 Pa).

Discussion

The FPTU static pressure differential measurements obtained during this study further support the results obtained by Bryant and Bryant, 2015. They had found a static differential fan pressure rise range of 0.20 – 0.27 in. w.g. (124 Pa) in a laboratory setting. The in-situ measurements of this study, though for a small sample of series FPTU, show very good agreement with that study.

CHAPTER VI

CONCLUSIONS AND FURTHER RESEARCH

The efforts by AHRI to update existing energy simulations of FPTU's raised the issue of quantifying the static pressure rise observed across FPTU's. This study (chapter 5) has confirmed the results obtained by Bryant and Bryant 2015's laboratory experiment with in-situ "field" observations. As was noted in chapter five however, further research in expanding the population of observed FPTU's – in terms of capacities, sizes, manufacturers and age – is warranted.

The in-situ experiments were expanded to include qualitative analyses of series and parallel FPTU leakage (Chapter 3). The study demonstrated that there is no significant evidence of series FPTU leakage, while a single parallel FPTU was observed to have leaked. Coupling that data set with the infrared (IR) images captured of pressurized FPTU's - usually considered normal operating conditions for parallel FPTU's - showing evidence of leakage along the FPTU "seams", induction port and interface connections. The implications towards comparative energy usage between series and parallel FPTU's as explored by Bryant et al, 2011 becomes more evident warranting further research into quantifying the amount of air leaking from the FPTU's.

The in-situ measurement also attempted to determine the validity of ANSI/AHRI 880 (section 7.2, 2011) in terms of "field" FPTU's (Chapter 4). The study determined that the minimum condition set (0.25 in. w.g. (62.2 Pa) downstream static pressure) is not representative of any of the FPTU's observed, with all the FPTU's operating well below the set standard. The implications regarding unit selection – "oversizing" airflow requirement, downstream air outlet performance and noise level performance – is another venue of further research.

The works of Yin and O'Neal 2014a and Bryant and Bryant 2015 independently quantified the two major inputs EnergyPlus requires to simulate FPTU's (static pressure rise across the FPTU and motor efficiency). Chapter 2 of this study presented the results of a series of energy simulations aimed at determining which combination of the two inputs – either within the quantified parameters or a combination of more extreme cases – contributed to observable differences in energy consumption. The

study concluded that the overall energy consumed by the simulated system does not change significantly, an observed difference of 2.3% annually between the greater extremes. EnergyPlus however simulates FPTU's as permanent split capacitor motors (PSC), similar analysis of electronically commutated motors was not in the scope of this study and warrants further research.

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